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# Optimal Placement and Sizing of Distributed Generation for Power Loss Reduction using Particle Swarm Optimization

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**Abstract**

This paper presents a new methodology using particle swarm optimization (PSO) for the placement of distributed generation (DG) in the radial distribution systems to reduce the power loss. Single DG placement is used to find the optimal DG location and its size which corresponding to the maximum loss reduction. The proposed method is tested on the 26-bus radial distribution system which modified from the Provincial Electricity Authority (PEA) distribution system. The total power is 8.49 MW and 5.97 MVAR and the power loss is 11.68 kW and 26.08 kVAR. The load flow analysis on distribution use forward-backward sweep methodology. The simulation results show that PSO can obtain the maximum power loss reductions.

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*Keywords:* Distribution Generator; Particle Swarm Optimization; Radial Distributed System

## 1. Introduction

PV distributed generation systems can make a positive contribution to the sustainability in developing countries that have access to electricity grid. Thailand is a tropical country and has plenty of sunshine [1]. Therefore, the country has abundant of solar resource to generate electricity. Integration of solar photovoltaic system with grid connection would assist in supplementing the continually increasing of electricity need in Thailand. Greater use of PV distributed generation systems can also increase reliability of the electricity grid. Many problems exist arising from the operation of PV distributed generators jointly with the grid. Particularly, optimal placement and sizing of such system need to be optimized for improving voltage support in distribution networks. Therefore, it is necessary to take into account optimal allocation and sizing of DG grid connected in distribution systems during the design stage.

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**Nomenclature**

| | |
|---|---|
| PV | photovoltaic |
| DG | distributed generation |
| PSO | particle swarm optimization |
| $P_i$ | net real power injection in bus *'i'* |
| $Q_i$ | net reactive power injection in bus *'i'* |
| $R_{ij}$ | the line resistance between bus *'i'* and *'j'* |
| $V_i$ | the voltage at bus *'i'* |
| $\delta_i$ | the angle at bus *'i'* |
| $Loss_k$ | distribution loss at section $k$ |
| $N_{SC}$ | the total number of sections |
| $P_L$ | the real power loss in the system |
| $P_{DGi}$ | the real power generation DG at bus $i$ |
| $P_{Di}$ | the power demand at bus $i$ |
| $c_1$ , $c_2$ | The weighting factor |
| $r_1$ , $r_2$ | the random numbers between 0 and 1, |
| $w$ | the weighting function, |
| $v_i^k$ | the current velocity of particle $i$ at iteration $k$, |
| $v_i^{k+1}$ | the modified velocity of particle $i$, |
| $s_i^k$ | the current position of particle $i$ at iteration $k$, |
| $s_i^{k+1}$ | the modified position of particle $i$, |
| $pbest_i$ | the personal best of particle $i$, |
| $gbest$ | the global best of the group. |

With the increase of distributed generation systems that are happening nowadays, the application of particle swarm technique which is the useful tool for system design and sizing for an actual feeder are presented in this study. The methodology applies the Particle Swarm Optimization (PSO) in order to minimize the system loss. Minimum system losses are obtained subjected to power constraint, voltage constraint and current limit.

The organization of this paper is as follows. Section 2 addresses the problem formulation. The PSO algorithm is represented in Section 3. A PSO computation procedure on for the OPDG problem is given in Section 4. Simulation result on the test systems are illustrated in Section 5. Then, the conclusion is given in Section 6.

## 2. Problem formulation

The real power loss reduction in a distribution system is required for efficient power system operation. The loss in the system can be calculated by equation (1) given the system operating condition [2].

$$P_L = \sum_{i=1}^{n} \sum_{j=1}^{n} A_{ij}\left(P_i P_j + Q_i Q_j\right) + B_{ij}\left(Q_i P_j - P_i Q_j\right) \tag{1}$$

where,

$$A_{ij} = \frac{R_{ij}\cos\left(\delta_i - \delta_j\right)}{V_i V_j}$$

$$B_{ij} = \frac{R_{ij}\sin\left(\delta_i - \delta_j\right)}{V_i V_j}$$

where, *Pi* and *Qi* are net real and reactive power injection in bus *'i'* respectively, *Rij* is the line resistance between bus *'i'* and *'j'*, *Vi* and *δi* are the voltage and angle at bus *'i'* respectively.
The objective of the placement technique is to minimize the total real power loss. Mathematically, the objective function can be written as:

$$\text{Minimize} \qquad P_L = \sum_{k=1}^{N_{SC}} Loss_k \tag{2}$$

Subject to the power balance constraints

$$\sum_{i=1}^{N} P_{DGi} = \sum_{i=1}^{N} P_{Di} + P_L \tag{3}$$

Voltage constraints: $$|V_i|^{\min} \le |V_i| \le |V_i|^{\max} \tag{4}$$

Current limits: $$|I_{ij}| \le |I_{ij}|^{\max} \tag{5}$$

where $Loss_k$ is distribution loss at section $k$, $N_{SC}$ is total number of sections, $P_L$ is the real power loss in the system, $P_{DGi}$ is the real power generation DG at bus $i$ and $P_{Di}$ is the power demand at bus $i$.

## 3. Particle swarm optimization

PSO is an optimization technique based on the movement and intelligence of swarms. PSO applies the concept of social interaction to problem solving. It was developed in 1995 by James Kennedy (social-psychologist) and Russell Eberhart (electrical engineer) [3]. Particle swarm is the system model or social structure of basic creature which make a group to have some purpose such as food searching. It is an important part to take the most of population in a group that has the same activity. The group of creatures has this relative behaviour, for example, bee swarm, fish school and bird flock.

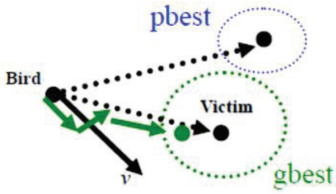


Fig. 1. Birds' food searching with PSO

Fig. 1 shows bird flock hunter that is a bird suspect to a particle [4]. In victim searching, all bird groups will fly together in the same direction and the bird leader is the nearest food that has the shortest distance as the best fitness and the other birds follow the leader. The particle swarm model will be used by fitness value consideration. The particles represent solutions of fitness value. Moreover the important property in food searching of birds for instance, the particle's velocity of each particle uses to set the direction of particle movement. After that, all particles in the flock would be improved their directions that related with the best fitness of particle direction. The result of this process thus helps to set the most appropriate direction.

PSO consists of a group (swarm) of individuals (particles) moving in the search space looking for the best solution. Each particle is represented by a vector *s* of length *n* indicating the position and has a velocity vector *v* used to update the current position which adjusts its flying according to its own flying experience as well as the flying experience of other particles. Each particle keeps track of its coordinates in the solution space which are associated with the best solution (fitness) that has achieved so far by that particle. This value is called personal best, *pbest*. Another best value that is tracked by the PSO is the best value obtained so far by any particle in the neighborhood of that particle. This value is called *gbest*. The basic concept of PSO lies in accelerating each particle toward its *pbest* and the *gbest* locations, with a random weighted acceleration at each time step as shown in Fig. 2. Each particle tries to modify its position using the following information with the flowchart of PSO algorithm as depicted in Fig. 3:

- the current positions,
- the current velocities,
- the distance between the current position and the *pbest*,
- the distance between the current position and the *gbest*.

The modification of the particle's position can be modelled by using equations (6) and (7):

$$v_i^{k+1} = wv_i^k + c_1 r_1(pbest_i - s_i^k) + c_2 r_2(gbest - s_i^k) \tag{6}$$

$$s_i^{k+1} = s_i^k + V_i^{k+1} \tag{7}$$

where,

$c_1$ , $c_2$: The weighting factor,

$r_1$ , $r_2$: The random numbers between 0 and 1,

$w$ : The weighting function,

$v_i^k$ : The current velocity of particle *i* at iteration *k*,

$v_i^{k+1}$ : The modified velocity of particle *i*,

$s_i^k$ : The current position of particle *i* at iteration *k*,

$s_i^{k+1}$ : The modified position of particle *i*,

$pbest_i$ : The personal best of particle *i*,

$gbest$ : The global best of the group.

AlRashidi M.R. and El- Hawary M.E. [5] have noted the advantages of PSO technique over other optimization techniques as follows:

- It is easy to implement and program with basic mathematical and logic operations,
- It can handle objective functions with stochastic nature, like in the case of representing one of optimization variables as random, and
- It does not require the good initial solution to start its iteration process.

However, the drawbacks of PSO technique still exist as follows [5]:

- More parameters tuning is required, and
- Programming skills are required to develop and modify the competing algorithm to suit different optimization problems.

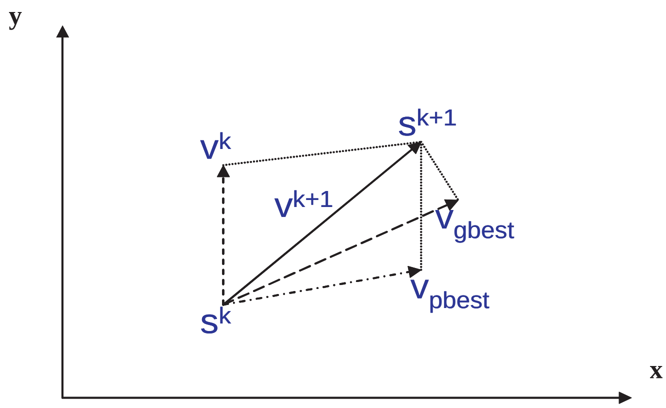


Fig. 2. Concept of modification of a searching point by PSO

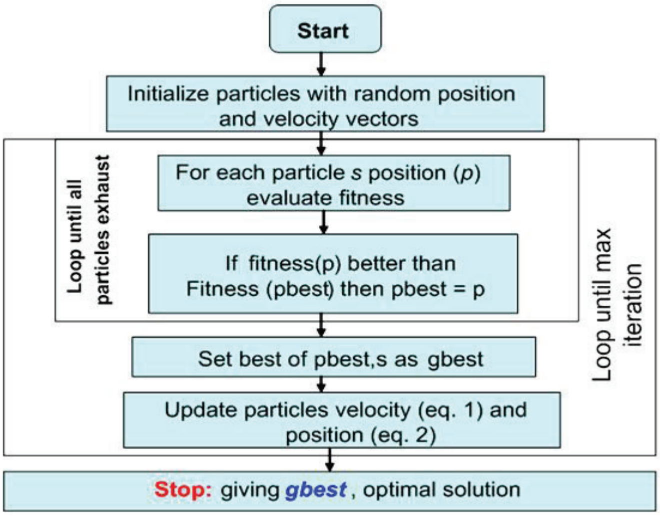


Fig. 3. Flowchart of PSO algorithm

## 4. Simulation procedure

The flowchart of the proposed algorithm is illustrated in Fig. 4 [6]. The PSO-based approach for solving the optimal placement of distributed generation problem to minimize the loss takes the following steps:

**Step 1:** Input line and bus data, and bus voltage limits.

**Step 2:** Calculate the loss using distribution load flow based on backward-forward sweep.

**Step 3:** Randomly generates an initial population (array) of particles with random positions and velocities on dimensions in the solution space. Set the iteration counter $k = 0$.

**Step 4:** For each particle if the bus voltage is within the limits, calculate the total loss using equation (1). Otherwise, that particle is infeasible.

**Step 5:** For each particle, compare its objective value with *the individual best*. If the objective value is lower than *Pbest*, set this value as the current *Pbest*, and record the corresponding particle position.

**Step 6:** Choose the particle associated with the minimum *individual best Pbest* of all particles, and set the value of this *Pbest* as the current *overall best Gbest*.

**Step 7:** Update the velocity and position of particle using equations (6) and (7) respectively. **Step 8:** If the iteration number reaches the maximum limit, go to Step 9. Otherwise, set iteration index $k = k + 1$, and go back to Step 4.

**Step 9:** Print out the optimal solution to the target problem. The best position includes the optimal locations and size of DG, and the corresponding fitness value representing the minimum power loss.

The PSO algorithm is able to reach a good solution by finite steps of evolution steps performed on a finite set of possible solutions. The objective function for the optimization is the power loss reduction as shown in equation (1). The PSO algorithm sets in the core of this optimization problem. This routine is programmed by MATLAB software.

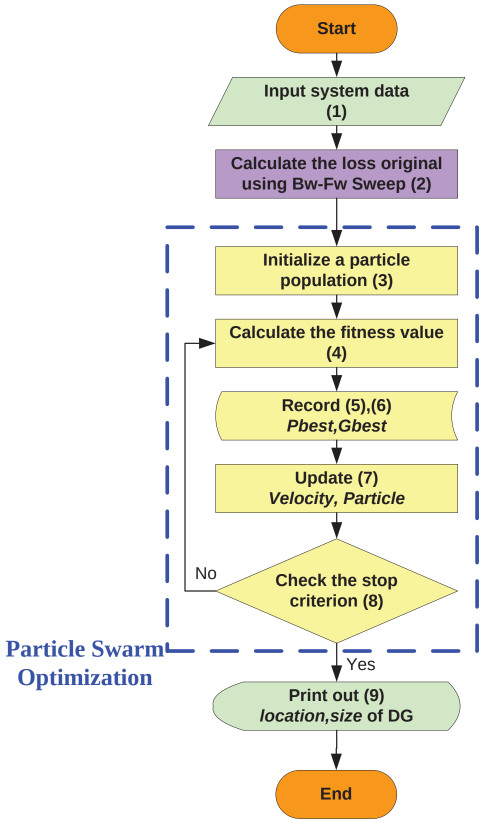


Fig. 4. PSO-OPDG computational procedure

## 5. Simulation results

The microgrid distribution system (22 kV) is used as a test system. A system was selected from one part of the PEA central station distribution network. The single line diagram of the network is illustrated in Fig. 5. The 26-bus system has 25 sections with the total load of 8.49 MW and 5.28 MVAR. The original total real and reactive power losses of the system are 11.68 kW (0.14%) and 26.08 kVAR (0.49%), respectively. The base MVA is 10 MVA and the base kV is 12.66 kV. For PSO parameters, population size=100, Maximum generation (*k*max) = 50. Following analysis is performed with the test system and results are presented accordingly.

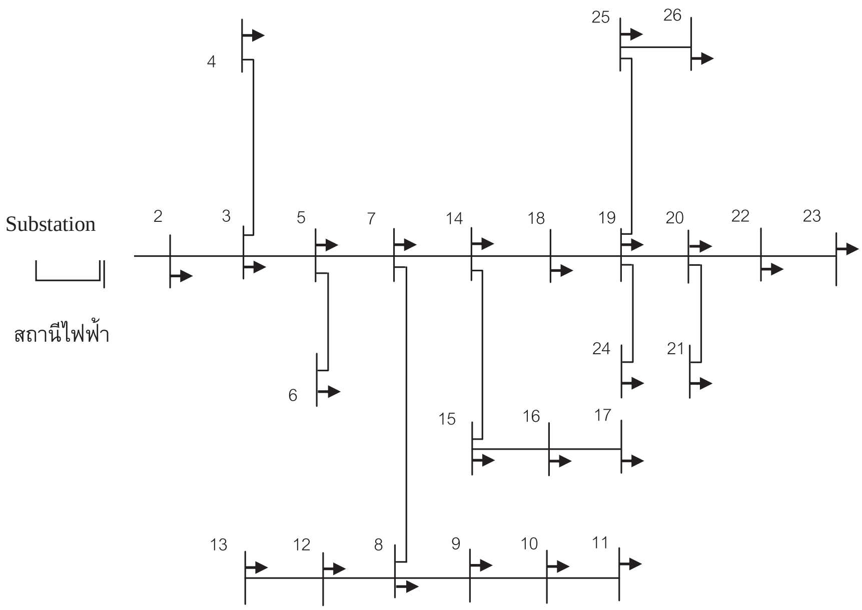


Fig. 5. A 26-bus radial distribution system

The proposed methodology was run on a 26 bus test system. The impact of installing DG in the case study network with optimal allocation and sizing is presented Table 1. The decrease in total power loss depends on the location and size of DG.

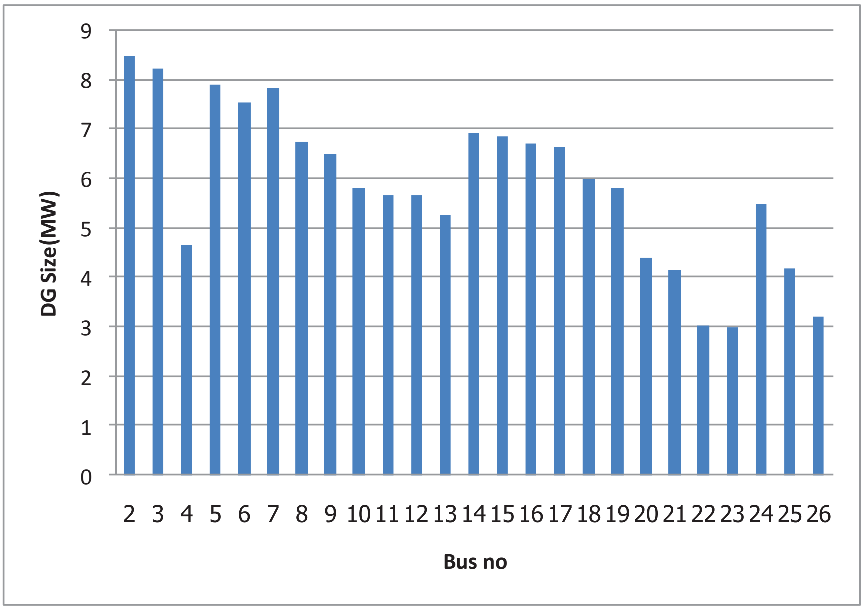


Fig. 6. Suitable DG size of a 26-bus test system

Fig. 6 shows the suitable DG size of a 26-bus test system and Fig. 7 shows the power loss of a 26-bus test system. The minimum power loss occurs in bus 14 (4.56 kW and 10.20 kVAR). The proposed method can reduce loss by 61% of its original loss.

Table 1. Results of a 26-bus test system

| **Bus Number** | **DG size (MW)** | **Ploss kW** | **Qloss kVar** |
|---|---|---|---|
| 2 | 8.5068 | 10.3580 | 23.6760 |
| 3 | 8.2344 | 7.1198 | 16.1569 |
| 4 | 4.6531 | 9.0117 | 18.2691 |
| 5 | 7.9300 | 5.0661 | 11.3894 |
| 6 | 7.5522 | 5.3662 | 12.1020 |
| 7 | 7.8500 | 4.7659 | 10.6897 |
| 8 | 6.7758 | 5.3157 | 11.7930 |
| 9 | 6.4996 | 5.5243 | 12.2208 |
| 10 | 5.8028 | 6.0993 | 13.4124 |
| 11 | 5.6693 | 6.2192 | 13.6618 |
| 12 | 5.6600 | 6.2339 | 13.6948 |
| 13 | 5.2773 | 6.5771 | 14.4206 |
| **14** | **6.9486** | **4.5639** | **10.2018** |
| 15 | 6.8565 | 4.6432 | 10.3937 |
| 16 | 6.7195 | 4.7710 | 10.6880 |
| 17 | 6.6535 | 4.8367 | 10.8430 |
| 18 | 5.9930 | 4.8258 | 10.7728 |
| 19 | 5.8276 | 4.8788 | 10.8882 |
| 20 | 4.4188 | 5.9701 | 13.3300 |
| 21 | 4.1434 | 6.2939 | 14.0584 |
| 22 | 3.0214 | 7.4594 | 16.6576 |
| 23 | 3.0127 | 7.4705 | 16.6838 |
| 24 | 5.4783 | 5.2687 | 11.7739 |
| 25 | 4.1968 | 6.5990 | 14.7698 |
| 26 | 3.2110 | 7.7178 | 17.2749 |

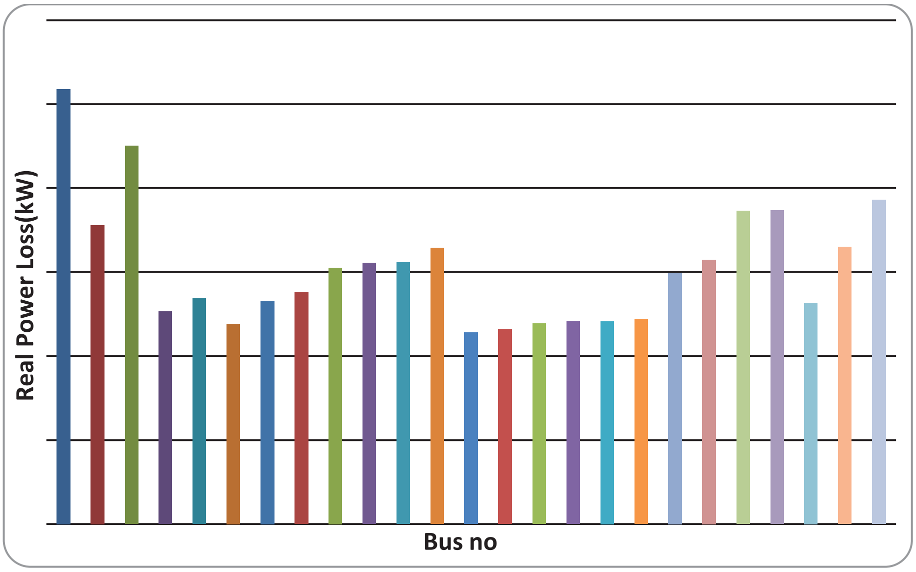


Fig. 7. Power loss of a 26-bus test system

Fig. 8 shows the voltage level comparison for the 26-bus system with and without installation of DG system. In order to have a clear comparison, bus voltages in the base case and also after installation of DG units are illustrated in Fig. 8. The outcomes represent that installation of DG units considerably improves the voltage profile. Note that installation of DG units give better average voltage levels (0.9985 per unit) compared with the original system (0.9977 per unit). In the system without DG units, the lowest voltage level is 0.9967 per unit. After the PV units are installed, the voltage level are improved (0.9977 per unit).

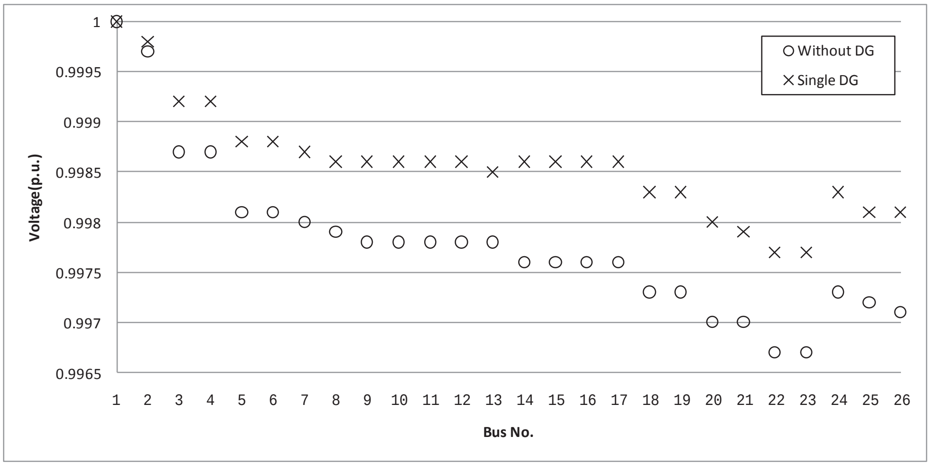


Fig. 8. Voltage level comparison on the 26-bus system

## 6. Conclusion

In this paper, a particle swarm optimization for optimal placement of DG is efficiently minimizing the total real power loss satisfying transmission line limits and constraints. The methodology is fast and accurate in determining the sizes and locations. The methodology is tested on a 26 bus systems. By installing DG at all potential locations, the total power loss of the system has been reduced drastically and the voltage profile of the system is also improved.


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